

The Engineering of Timber Highway Structures

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You have all had experience in the use of timber as a material of construction. Many of you, perhaps, are thoroughly versed in the technical aspects of timber design. It is not possible, in the time we have to discuss such a broad subject, to try to cover the details of timber design and construction. That can be obtained at your convenience from easily obtainable and authoritative literature published by the U. S. Forest Products Laboratory, such as its *Wood Handbook* and *Technical Bulletins*, by colleges, and by engineering and construction organizations whose business depends on the correct use of timber products.

Technical knowledge, as you know, is based on observation and experiment, correlated by theoretical analysis. A great amount of factual data has been recorded in technical publications like those I have mentioned, but with timber, as with all other construction materials, research is never ending. New facts about the properties of the material are being discovered and new ways of fabricating and using it are being developed.

Progress depends on quick and efficient spreading of information among those who need it, and meetings such as this afford an opportunity for us to exchange the knowledge we have picked up through our own experience.

Therefore, I propose to tell something of our experience with timber bridges in California. In order to do this it is advisable to describe the conditions there sufficiently to give you the background of our engineering experience.

Prior to 1925 the highway department of California maintained only such sections of State highway as had been built under its own supervision, and a few county-built bridges that were accepted as conforming to State standards. In January, 1926, in accordance with a new law, the State took over for maintenance the best traversable route

following each state highway. With these roads it had to take over for maintenance a large number of timber and other bridges of all kinds and conditions. A year or so thereafter, the first inventory and inspection of all bridges on the State highway system was made, with just sufficient detail to obtain a general idea of their condition and strength and to select those structures in need of immediate attention.

At the time this was done, heavy commercial vehicles had just started on the way to their present development—both as to their number and concentrations of axle loads. The mileage of State highways was then less than half of what it is now and gas-tax funds available for reconstruction were relatively much greater. The legal responsibility placed by the laws of California on State highway officials for determining the safe load the bridges could carry had not been fully realized, and further investigation of the bridges was limited for a time to obtaining data for the most needed repair and reconstruction work.

Considerable improvement had been made in the condition of these bridges when, in 1931 and more particularly in 1933, an additional mileage of county roads was taken into the highway system, practically doubling the mileage up to that time. These added roads were largely of secondary importance and, consequently, the bridges on them were generally of lower standard and in poorer condition than those on the roads of the original system. The effect of the increasing truck weight concentrations was also being felt; in fact, several light steel spans with timber floors collapsed primarily because of careless operation of a vehicle, but fortunately without loss of life or serious injury. These occurrences brought home the serious possibilities in case such an accident should result fatally, and particularly if it should be of a spectacular nature.

A larger and more completely equipped organization was then deemed necessary properly to take care of the situation that had arisen. What we call our maintenance and research or "investigation" section of the bridge department was formed, which periodically inspects all the bridges, recommends repairs and replacements as they are needed, and gathers technical information bearing on improvements in design and maintenance.

We learn largely through our failures, or through difficulties that result from improper use of any construction material. A structure that is serving satisfactorily seldom gets much attention in order to find out if it can be improved. Very often, there is a tendency to avoid publicity in case of a failure, but we as engineers are aware that

perfection is far from attainable. What may be tops today is obsolete tomorrow. We have tried to obtain a record of all cases where design or choice of material has been faulty or where improvements seem possible. Because the California State bridge department not only designs but supervises the construction and maintenance of its bridges, it is in a fortunate position to observe closely the results of its own design practice.

There are several factors that affect the serviceability and economic use of timber structures. These must be kept in mind when weighing the evidence obtained from field inspections if we are to get the greatest benefit from them.

1. The treatment and kind of wood.
2. Climatic conditions, moisture and temperature.
3. Soil conditions, continually or periodically wet, alkali, etc.
4. Frequency of heavy loads and other traffic conditions.
5. Quality of maintenance, faulty design, details, etc.

Because California is adjacent to the great Douglas fir forests of Oregon and Washington and has great timber resources itself, it has made use of structural timber in many types of bridge construction. Redwood, being a California product, has been used frequently. Douglas fir is used both treated and untreated, but cresote pressure treatment is the usual practice. Occasionally other woods, such as Cedar, and even California red fir, and Ponderosa Pine, are used. (Fir and pine have been used by some counties, but not by the State, except in special cases for temporary structures.)

Officially, the sun always shines in California; but off the record, it must be admitted that California, as well as the other Pacific Coast states, has a great variety in climate and other local conditions which affect the service life of timber structures. Along the coast and at points in the Coast Range, rainfall is heavy, except during the summer. In the interior valleys it rains from 10 to 20 inches a year, with hot summers; in the Sierras there is heavy snowfall; and in the eastern "desert" country there is heat and drought. As to soil conditions, there is everything from tideland marsh to the dry sandy soil of the desert. Alkali is present in the soil of many locations and has been found to affect the life of timber in contact with the soil very materially and in unexpected ways.

Many inaccessible areas in California are not served by railroads or even by main highways, and there are heavily populated areas such as the Los Angeles Metropolitan District or the San Francisco Bay Area.

In general, it would be hard to find a condition in any other state that is not approximated by the conditions found in some part of California.

Taking up first the short-span, trestle type of structure, it is best to think of them as made up of several distinct and separate parts that have their individual problems:

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| 1. Abutments | 3. Posts, caps, and stringers |
| 2. Piling or sills | 4. Floor |

Abutments and piling, or sills, have to be in contact with the ground. Now, untreated timbers of all species are subject to decay under certain conditions of moisture and temperature, and contact with the ground is very likely to produce these conditions. Therefore, relatively early decay of any untreated, commercially obtainable timber may be expected under these circumstances. Other portions, where the wood is well ventilated and particularly if it is subjected to long periods of hot drying weather, will have a relatively long life. The avoiding of conditions that prevent the proper drying out of timbers is an important part of the design. Keeping the ends of timbers free from dirt and debris is a necessity. The results of otherwise good design and maintenance are often nullified by such well-intentioned practices as painting green lumber on all sides to "protect" it. There is probably no surer way than this to give decay a chance to start or hasten its progress if it does start. It is evident that with any kind of wood, particularly if untreated, one part of a structure may have a very different service life from another, and the service life of the structure as a whole will be governed by that of the shorter-lived portion. While there will be some salvage from the longer lasting portion, and under the circumstances it may be desirable to salvage timbers in good or fair condition rather than throw them away, there is seldom much profit in salvaged lumber after it has been put in shape to use again, handled, and transported to where it is needed.

For the substructures of modern standard timber trestle spans California has used creosoted Douglas fir or redwood piles and bulk-heads, as well as concrete abutments, sills, or pedestals. When there is contact with ground, consistently satisfactory results have been obtained only by the use of concrete or creosoted timber. In the case of the floor and stringers, the question of durability is usually secondary to strength and resistance to wear and tear. Depending on traffic conditions, and lately, on the availability of material, timber floors (double layer plank or laminated strips) with an asphalt surface or concrete slabs have been used. Oregon has used with success a subfloor

of planks with spaces between them, with two-inch by two-inch Port Orford Cedar strips instead of the usual laminations. For subfloors under concrete slabs California first used two-inch redwood planks, then one-inch sheeting, and latterly plywood and thin sheet iron. The use of sheet iron or thin plywood, which serves merely as a form on which to place the concrete, seems to be generally satisfactory. Some states take advantage of the composite action of the concrete slab and timber stringers by suitable shear devices. Difficulty has been experienced from time settlement of timber stringers and, sometimes, the curling of concrete slabs, which produces a rough riding condition for cars traveling on high-speed highways. As you know, timber deflects after a period of time under a steady load, and this deflection about equals the deflection when the load was applied. This has been taken care of by placing an initial camber in the floor around $3/16$ ths of an inch for a 19-foot span—and by putting the joints every two spans. Serious trouble with the laminated type of floor has resulted from the use of green timber which afterward shrinks and causes the nailing to become loose. It has not been practicable to obtain properly seasoned timber at reasonable cost. Shrinkage caused by excessive drying of the floors of trestles in the desert regions actually allowed the surfacing to be forced down between the laminations. This resulted in wearing the flooring and the tops of stringers so that they looked like pieces of wood worn round and smooth from the action of gravel in the stream bed. Because of this loosening-up, the use of a concrete slab wearing surface on timber stringers has proved very satisfactory, although laminated floors of creosoted timber are also giving good service. The choice, probably, is a matter of relative first cost.

The design of trestle superstructures is a development from the days when primitive man dropped logs across a stream for a foot bridge. When vehicles came into use and wider bridges were needed, several logs were laid side by side and saplings laid across for a floor. The size of the logs was determined by judgment based on past experience. Then came sawed stringers and planks for floors, but with all man's knowledge there has been little improvement in the methods of designing timber-trestle highway spans. The computations by which engineers have determined the sizes of the timbers have only a vague relation to the actual strength of the floor as a whole. It usually results in obtaining a good safe bridge for the expected conditions. The matter of too much timber in one part and not enough in another was not serious so long as lumber was cheap and wear and tear was light. Now that economic competition from other materials is keener and the wracking

under heavy truck loads is severe, more logical and scientific design practice has become necessary. Tests have shown how to determine the maximum required strength of stringers in shear (shear is usually the governing stress), but the problem of how axle weights are distributed to the stringers is not yet solved. The bridge committee of the American Association of State Highway Officials is now studying it in connection with the revision of its specifications. Timber engineers are also tackling this and other like problems, a fact which indicates that some reasonable answer will be forthcoming soon.

The so-called "working" stresses are now being given the once over. They have recently been raised in conjunction with the effort to save critical material. This is being done after a careful study although, because of war conditions, the quality of material is often less dependable than it normally would be.

However, many factors have to be considered in determining the safety factor of a timber bridge besides the working stress. The actual distribution of the forces among the various members under ideal conditions is, as already stated, not too well known. Reasonable assurance that decay, shrinkage, and loosening-up of bolts and nails will not lower the ability of the members to act together as a whole must be had. Designs must be based on actual highway loadings, not hypothetical loads giving different safety factors for different members and span lengths. If such factors are taken care of, then experience shows that timber undoubtedly can be stressed more highly than present practice permits. That there has been a problem to be solved is indicated by the fact that in one case an old timber bridge may carry several times its standard design loading without damage and yet stringers in a modern structure may break under loads little heavier than normal.

In arriving at the present working-stress values, every adverse factor has been assumed to occur simultaneously in the maximum amounts indicated by tests. The laws of probability indicate that the possibility of such a combination is negligible. It would also appear unreasonable to apply the same value for lower strength under long continued loading to a warehouse and to a bridge. In the first case, the so-called live load is practically continuous; whereas a highway bridge is almost never heavily loaded for any appreciable length of time. Another item in the determination of a proper safety factor is the allowance to be made for lower-than-average breaking strength of individual pieces of wood. This involves the variation in strength of clear pieces of wood as well as reductions in strength for knots and checks.

A great deal of information has recently been obtained on these factors, but it seems that the final answer is closely related to the dependability of lumber gradings and the use of built-up members. By using several smaller pieces to their best advantage, definite strength values are more certain than with one large piece, and a better grade of wood can be had at lower cost.

The serviceability of various types of floors for timber truss-and-arch spans is affected by the same conditions as trestle superstructures, but the trusses and arches have their own problems.

In the early days the railroads of the West made considerable use of timber-truss spans. Timber was plentiful and cheap, and trusses were designed high and with short panels. Capable timber men were likewise obtainable for a relatively small wage, and the framing was of a high quality. The results were very satisfactory. In later times, as timber became more expensive and it became difficult to be certain of getting satisfactory workmanship on the framing of the members, designers attempted to overcome the difficulty by using fewer truss members of consequently larger size and less framing at the joints by the use of angle bearing blocks. The result was unsatisfactory, probably because of the rigidity of the truss joints produced by such large stiff members and often because of eccentric bearing. Shearing at the joints and even the breaking in half of lower chord members resulted from such designs, and it looked for a while that timber trusses under modern heavy traffic conditions were on the way out. However, the advent of the timber connector has brought about a design with efficient connections. Furthermore, the members are composed of smaller pieces and the entire truss acts more in accordance with the way it is figured to act. This method of building timber frames has made the construction of long spans practicable and efficient.

In 1934 and later, several arch-and-truss spans were designed and built by the California Division of Highways, using some of the earliest ring and alligator connectors. At first about the only references our designers had for this type of construction were German texts; but for all of that, the structures have given satisfactory service to date. The most outstanding of them, a bridge over Dolan Creek on the coast of Monterey County, has a 180-foot arch span, four built-up timber girder spans 28 feet long, and several 19-foot trestle spans. It was prefabricated and fitted together in a yard near the City of Monterey and then taken to the site some 45 miles south and erected in sections. Although the cost of erection was somewhat high, as might be expected in a pioneer work like this, the results obtained indicated

that dependable long-span timber bridges were practicable and, under proper circumstances, economical.

There is little doubt now that the advent of timber connectors, such as the split ring, toothed ring, shear plate, and claw plate, has modernized timber structures. By their use the construction of joints between members has been simplified; the necessity of making complicated scarfs and tabled joints whose efficiency is dependent on the skill and care of the workman is eliminated as the hole bored for the bolt locates the joint in all members with absolute accuracy. The four types of connectors have distinct uses.

Split rings and tooth rings provide a mechanical shear connection between the faces of any two pieces. The split rings transmit a greater amount of stress than the toothed rings and are much easier to install, which makes them more economical even though the price may be a little higher.

The toothed rings may be useful in repair work where it is difficult to locate and cut the necessary grooves to install split rings.

Shear plates transmit stresses between faces of any two timbers or between the face of a timber piece and a steel plate or strap, making use of the large bearing area in the timber and shear strength of the connecting bolt. The use of this device provides a means of making easily connected field joints for the erection of pre-assembled sections, anchorage of timber members to foundations and the joining of members to steel gussets. This improvement in making splices removes one of the greatest weaknesses in truss spans: the lower chord splice.

Claw plates are primarily of use with piling on such structures as wharves, piers, and trestles.

The system used in assembling the members of timber-connected structures must be selected with care. Only those types of trusses or frames having not more than two web members connecting to a main member at a panel point should be used. The end post connection of a through Pratt truss or the introduction of verticals in a Warren truss would give a designer a great deal of trouble in developing the connections. A Fink truss is a veritable headache unless gusset plates are used. Many designers have discovered too late to change design that too many members at a joint create trouble, and they have tried to obviate it by connecting one or more of the members eccentrically at the panel point. This introduces bending moment and indeterminate secondary stresses, which have caused members to split at the ends.¹

¹ *Civil Engineering*, Vol. 13, No. 12, December, 1943.

Care should be exercised in designing and detailing to assemble all major joints concentrically.

While the timber-connector method solves most of the mechanical difficulties connected with truss design, it does not lend itself to easy repair in case of decay at the joints. Creosoted timber prefabricated before treatment seems to be the only answer at present.

Span limitations have never been definitely determined, but it is usually conceded that for trestle spans nineteen feet is the most economical—not over about twenty-five feet. Trusses of 200-foot span are not unknown, and 250 feet is entirely possible. Arches of 200 feet frequently are seen and 300 feet have been contemplated.

With the advent of wide roadways, timber floorbeams became an increasingly difficult problem. There are two methods of solving this: by building trussed floorbeams, or by laminating and gluing. The use of glue opens up a possibility of assembling boards or planks into a more efficient structural shape, such as an eyebeam section, saving both material and dead weight.

The mention of laminated glued construction may be met with some doubt as to its adequacy, but it is an established fact that any good glue will make a joint stronger than the wood itself when properly handled. A waterproof glue must be used that will withstand the exposures encountered by highway structures. Such glues are those of synthetic resins and are related to the plastics which have become so prevalent. Proof of the effectiveness of these glues is in their use in Navy and Coast Guard ships. Keels and stems are being laminated from thin boards, bent and glued to form a single homogeneous unit, lighter in weight and without the weakening effect of a joint between two separate pieces as formerly used. The famous P.T. boats of the Navy use a plywood skin that is glued with these waterproof glues.

The possibilities of laminated glued construction open up an entirely new field for timber. Architecturally pleasing arches and rigid frame bents of many shapes and spans, as well as large-sized long members like the floorbeams mentioned, can be made readily. An advantage of laminated sections is that the material used, one- or two-inch boards, is dry. This eliminates the unsightly checking which is inherent in large timbers.

Those who are interested in promoting the use of timber as a construction material are aware of the competition they have to face from other forms of construction. Their engineers have worked out and collected in convenient form the data necessary to produce efficient designs. The lumberman who, in the past, has been faced with the problem that for every stringer he cuts he must cut and sell eight or

ten times as much small-sized stock, is better pleased with the newer order.

We are interested in maintaining competitive conditions in the construction industry. They lead to more progress in the art of construction and to more economical structures. It is the duty of engineers responsible for the design of highway bridges to see that they keep up to date on new developments in all forms of construction. Timber construction has shown a development in recent years that is worth looking into. To take proper advantage of what the timber people have to offer, we must see that timber is used only where it will serve with economy and that proper attention is paid to construction details that prolong its service life even in the simpler types of structure.